Theses of doctoral (PhD) dissertation

ANALYSIS OF THE INTERACTION OF ARTIFICIAL FERTILISATION AND IRRIGATION IN MAIZE PRODUCTION

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1. PRELIMINARIES AND OBJECTIVES OF THE DOCTORAL THESIS

Field crop production is of fundamental importance for the feeding of human population; industrial crop synthetize carbohydrates, proteins and oils from the light energy of solar radiation which are essential for human and farm animal consumption. In industrially advanced countries, a decreasing proportion of the population deals with the food production.

Increasing agricultural production is inevitable for the feeding of global human population; it can be secured only through the increasing use of irrigation water and mineral fertilizers (*Yang et al.*, 2006). Global population has increases by 8.7% between 2005 and 2012 and it has been 7.08 billion in 2014 (*Statisztikai tükör*, 2014), therefore increasing yields of maize and improvement of production security are more and more required. Qualitative factors also need to be taken into consideration, since consumption value is determined by the nutritional composition. Increasing yields can be achieved through appropriate nutriment management, however the issue of production security depends on proper water management.

The objective of fertilization is the nutriment supply of crops, protection of the soil fertility, stabilisation and increase of yields and improvement of nutritional quality. However, nitrogen washed out due to improper nutriment supply threatens surface waters and underground water stocks (*OECD*, 1982; *Smith*, 1998; *Barton and Colmer*, 2006; *Aparicio et al.*, 2008). Nitrate pollution is one of the most serious global problems, as high nitrate content on drinking water has adverse effects on human health (*Weisenburger*, 1991). Consumption of drinking water with high nitrate content might cause methemoglobinemia or Blue Child Syndrome (*Sasson*, 1993), spontaneous miscarriage (*Nolan*, 1999) and different forms of cancer (*Weisenburger*, 1991). Therefore, the determination of fertilizer dosages suitable for the production site, plant and production year is important.

Due to the reduction of leaching it is necessary to divide nitrogen fertilizers. Determination of proper basal fertilisation and top dressing doses is more and more important not only environmentally, but economically as well.

Long-term field trials are required for the observation of nutriment conversion and the long-term effects of climate change. In agriculture, decision-making requires a large amount of data (*Milic*s, 2015). An effective method for spatial and temporal data management are the geographic information systems (GIS) (*Dobos et al.*, 2004). Information demand in terms of the soil of the production site is as old as the scientific research of agriculture. (*Pásztor and Szabó,* 2006). Soil properties can be concluded form yield maps and with their help working hypotheses can be set up in the scope of long-term trials.

Effectiveness of plant production and maize production is determined by the genotype and primarily by the available supply of water and nutriments, as well as the application time and distribution of the used nutriments. Professional fertilisation is one of the essential requirements of optimal plant production; if we are fully aware of the phenomena taking place within the soil we still do not get overall answers in terms of the nourishment level of the plant. Therefore, plant analysis is essential besides soil analysis. The analysis of the effects of irrigation, nutriment conversion, production year and climate change requires long-term field trials, by means of which all of these parameters can be. Besides the analyses, the spatial visualisation of the plot-level data might also be necessary for heterogeneity analysis or presentation.

Main objectives of the analyses:

- analysis of the conversion of basal fertiliser and top dressing by means of SPAD measurements in different versions of irrigation, by means of novel statistical methods;

- analysis of the phenological phases and the effect of irrigation on maize plants by means of SPAD measurements;

- effects of fertilisation, irrigation and genotype on the maize yields;

- analysis of the effects of artificial fertilisation and production year on yields by means of novel methods;

- artificial fertilisation-related technical advice, methodology development;

- elaboration of a new and utilisable method for the proper spatial and temporal storage and visualisation of the long-term field trial data.

2. MATERIAL AND METHOD

2.1. CHARACTERISATION OF THE TRIAL

The measurements have been carried out at the Látókép Experimental Station of Plant Production of the Farm and Regional Research Institute of the Institutes for Agricultural Research and Educational Farm of the University of Debrecen (47° 33’ N, 21° 26’ S, 111 m), in a moderately warm and dry production area in 2012−2014. The trial is on split-strip-plots and has two repetitions. On the main plots the hybrids, while on the split plots the irrigated/non-irrigated variables can be found as well as the different artificial fertiliser dosages. Plant number is 73,000 ha^{-1}. The green crop has been maize. The applied artificial fertiliser was 27% MAS (Genezis) in every production year, namely NH_4NO_3 + CaMg $(CO_3)_2$. Its exact composition:: 27% nitrogen (N) in the form of ammonia (NH_4) and nitrate (NO_3) in a 1:1 ratio, 5% calcium (Ca), which is 7% CaO expressed in calcium-oxide, 3% magnesium (Mg), which is 5% MgO expressed in magnesium-oxide. Irrigation of the trial was provided by a Valley linear with a water amount corresponding to the demands of the given production year.

Artificial fertilisers have been split to basal fertilisers and top dressings.

−Basal fertiliser: $A_{(0)}$= untreated control; $A_{(60)}$=60 kg N ha^{-1}; $A_{(120)}$= 120 kg N ha^{-1},

−Top dressing in the V6 phenophase: $V6_{(90)}$=$A_{(60)}$+30 kg N ha-1; $V6_{(150)}$=$A_{(120)}$+30 kg N ha^{-1},

− Top dressing in the V12 phenophase: $V12_{(120)}$=$V6_{(90)}$+30 kg N ha^{-1}; $V12_{(180)}$=$V6_{(150)}$+30 kg N ha^{-1}.

2.2. MEASUREMENTS OF CHLOROPHYLL CONTENT

Similarly to numerous other researchers (*Yadava*, 1986; *Schepers et al*, 1992; *Piekielek and Fox,* 1992, *Berzsenyi and Lap*, 2003b; *Ványiné*, 2008), relative chlorophyll content measurements have been carried out by means of a SPAD-502 chlorophyll measuring device. Three plants have been measured on each plot, on the highest fully developed leaf in phases V6 (*Ritchie et al.*, 1997) and V12, while on the leaf opposite to the ear in phase R1 (*Costa et al.*, 2001). The measurement took place on the 6^{th}, 7^{th} and 8^{th} plant of the second row from the left of every plot.

HARVESTING, YIELD AND MOSITURE MEASUREMENT

The trial has been carried out with a Sampo 2010 combine harvester; yield per plot has been measured with the built-in scales and sampling for the later nutritive value measurement was carried out here as well. The kg/plot yield values have been recalculated with a 15% moisture content to t/ha unit of measure.

APPLIED STAISTICAL METHODS

Statistical analysis and the elaboration of the interaction graphs have been carried out in an R 3.2.4. statistical environment (*R Core Team*, 2016) with the RStudio (*RStudio Team*, 2016) graphic surface, y using the "gplots" (*Warnes et. al*., 2015), "car" (*Fox and Weisberg*, 2011) and "agricolae" (*de Mendiburu*, 2016) packages. Charts have been made by means of Ms Excel 2010.

For the analysis of the connection between artificial fertilisation and relative chlorophyll concentrations and for the analysis of irrigation and relative chlorophyll concentrations a repeated measurement model has been created based on the example of *Huzsvai and Balogh* (2015). To analyse the connection of artificial fertilisation and yield, analysis of variance has been carried out, by means of the model of *Huzsvai* (2013). The mean value comparison of the measured SPAD-values and yield data has been carried out by means of the method of Student – Newman – Keuls (SNK), in which the smallest significant difference has been determined. Linear regression analysis has been carried out for the analysis of the connection of the measured is Chl-values and the yield.

VISUALISATION OF TRIAL DATA WITH THE HELP OF GIS ENVIRONMENT

For data input within a GIS environment and its visualisation Quantum GIS-t (*Quantum GIS Development Team*, 2016) has been applied. The outlines of the plots have been recorded with GPS and the distribution maps for each plot have been completed by means of the Quantum GIS 2.8.1. GIS software and its „OpenLayersPlugin" module (*Kalberer and Walker*, 2014). Within the „OpenLayers Plugin" the map layer of „Google Satellite" has been used (*Google*, 2016). OpenOffice Calc software has been used for data input which is a cost-free alternative of Ms Excel. Distribution maps have been elaborated with the built-in categorisation of QGIS by using the appropriate attribute column, which have been used in the thesis as .png extension images.

3. RESULTS

3.1. EFFECT OF BASAL FERTILISATION AND TOP DRESSING, IRRIGATION AND PHENOLOGICAL PHASES ON THE CHLOROPHYLL CONCENTRATION OF MAIZE IN DIFFERENT PRODUCTION YEARS

In **2012**, at the phenological phase of 6 leaves, lower SPAD values have been measured in the non-fertilised control plots than in the ones treat with artificial fertiliser (Figure 1). Under non-irrigated circumstance, there was no difference amongst the SPAD values of plots treated with artificial fertiliser. However, under irrigated circumstances the values of plots treated with 120 kg N ha^{-1} basal fertiliser are higher.

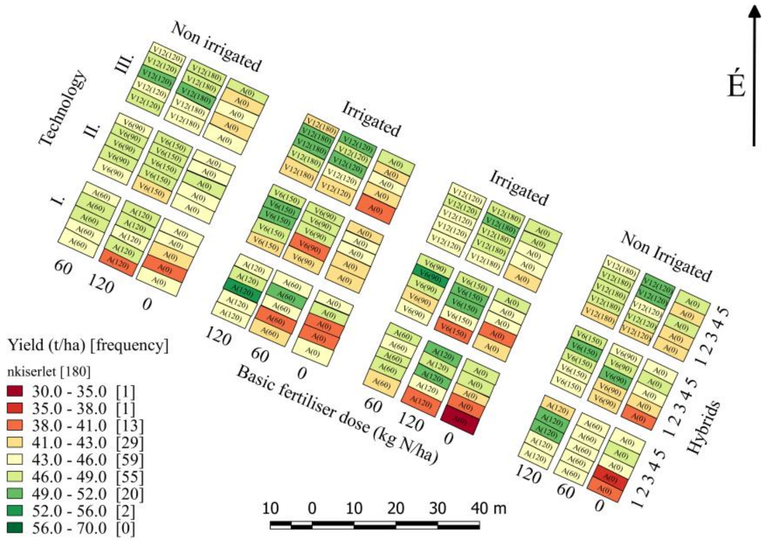

Figure 1: Spatial distribution of SPAD-values at 6 leaf phase (Látókép, 2012)

At 12 leaf phase, higher SPAD values have been recorded in the case of top dressing treatments with larger doses. However, the effect of top dressings applied at 12 leaf stage is best observable here, since it has not been utilised during the period between the time of measurements and the top dressing treatment (Figure 2).

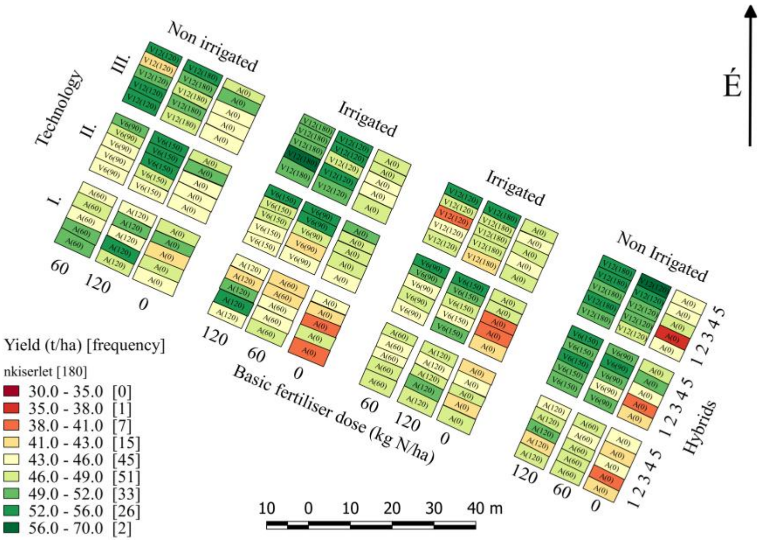

Figure 2: Spatial distribution of SPAD-values at 12 leaf phase (Látókép, 2012)

In the case of production year 2**012**, the chlorophyll content growing effect of top dressing applied during the **R1** phase is already visible on the map. On the $A_{(60)}$ plots which have been treated with 60 kg N ha^{-1} basal fertiliser, measured SPAD values are well separable from the larger dose artificial fertiliser treatments (Figure 3). Higher SPAD-values have been measured in the case of treatments with doses larger than A 120 kg N ha^{-1}.

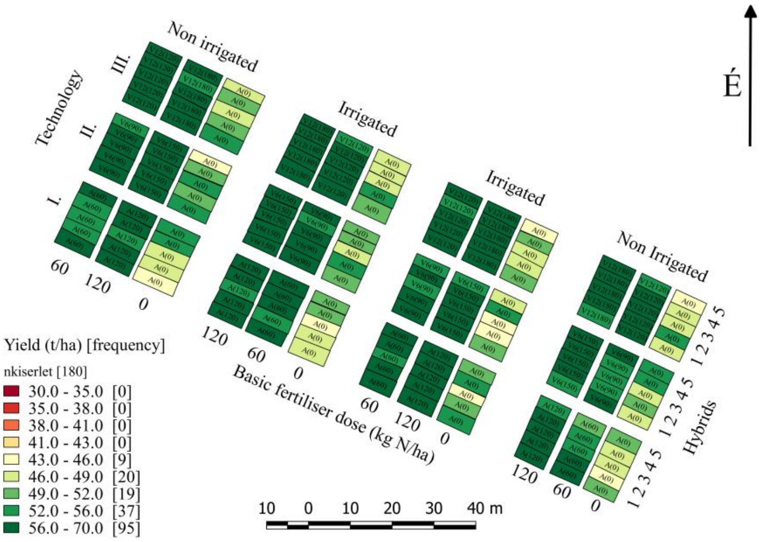

Figure 3: Spatial distribution of SPAD values during the phase of 50% silking (Látókép, 2012)

In the course of statistical analysis, the effect of artificial fertiliser treatments on SPAD values in **2012** under irrigated and non-irrigated circumstances have been analysed separately. On *non-irrigated* plots, artificial fertiliser treatments, the phenological phase and their interactions had a significant ($P<0.001$) influence on SPAD-values. On the basis of the post hoc test it is it can be said that in 2012 every treatment has significantly ($P<0.001$) increased chlorophyll concentration in comparison with the non-fertilised control. Homogenous groups are marked with identical colours. In the case of the $A_{(60)}$ treatment, the measured SPAD values have been 2.6 higher than on the control plots. In the $V6_{(90)}$ treatment, a significantly higher (1.3) chlorophyll content has been measured than in the case of the $A_{(60)}$ treatment. There was no statistically detectable difference between the $V6_{(90)}$ and the $A_{(120)}$ treatments. $V12_{(120)}$, $V6_{(150)}$ and $V12_{(180)}$ treatments formed a separate group, because they have not differed from each other, but they significantly have from every other treatment. The highest SPAD values (52.25) have been measured in the case of the $V12_{(180)}$ treatment, which had the largest dose of basal fertiliser (120 kg N ha^{-1})+30+30 kg N ha^{-1} top dressing. The $V12_{(120)}$ treatment significantly (by 1.69 SPAD value) increased chlorophyll concentration in comparison with the $A_{(120)}$ treatment. Based on the above, the 60 kg N ha^{-1} basal fertiliser +30 +30 kg N ha^{-1} top dressing had a better conversion rate under non-irrigated circumstances than the 120 kg N ha^{-1} basal fertiliser.

As confirmed by the post hoc test, chlorophyll concentration has increased within the plant during growth, the lowest SPAD-value (45.34) has been measured during the 6 leaf stage. Relative chlorophyll concentrations measured during the 12 leaf stage have been (statistically confirmed) 2.65 SPAD-values higher than during the 6 leaf stage. The highest values have been measured during the R1 phenophase, which was significantly higher than the values measured during the other two phenophases.

The effect of the phenological phase and artificial fertilisation on SPAD-values has been analysed. Over the vegetation period, chlorophyll content has increased in the leaves (Figure 4), therefore chlorophyll concentration increases in different phenological phases even with the same treatment. Identical fertiliser treatments are marked with the same colour. On the basis of the post hoc test, every fertiliser treatment differs from the untreated control plot in all three phenological phases. Interaction of fertilisation and the phenological phase has also been analysed. The chart shows that chlorophyll concentrations have been influenced more by phenological phases than by fertilisation. The lowest SPAD value (43.81) has been measured during the 6 leaf phase with the $A_{(0)}$ treatment; it has not differed significantly from the $A_{(60)}$, $A_{(120)}$, $V6_{(90)}$ fertiliser treatments. Within the 6 leaf phase, $V12_{(180)}$, $V6_{(150)}$ and $V12_{(120)}$ treatments form a separate group, which has a statistically verifiable difference from the non-fertilised control plots. During the 12 leaf stage, the lowest SPAD value (45.55) has been measured on the non-fertilised plots. This value does not differ significantly from the values measured in the case of the $_{(60)}$, $A_{(120)}$ and $V6_{(90)}$ treatments also during the 12 leaf phase. The difference between the groups of $V6_{(150)}$, $V12_{(120)}$, $V12_{(180)}$ and $A_{(60)}$, $A_{(120)}$, $V6_{(90)}$ was statistically verifiable. However, the values of the $V6_{(150)}$, $V12_{(120)}$ and $V12_{(180)}$ treatment group measured during 12 leaf phase have not been different from the values measured on the control plots during the R1 phase. Higher SPAD values have been measured during the 50% silking phase, except for the non-fertilised control plots. The highest SPAD value (58.85) has been measured in the case of the $V6_{(150)}$ treatment, which has not differed significantly from the $V12_{(180)}$, $V12_{(120)}$, $A_{(120)}$, and $V6_{(90)}$ treatments, namely they formed a group within the Student – Newman – Keuls test. Within the R1 phenophase the $A_{(60)}$ differed significantly from this group. The values measured in this fertiliser treatment (55.26) belong to the recommended maximum SPAD value range of 52-56 according to *Piekielek et al.* (1995), when maize has not response to the effect of the additional nitrogen fertiliser. Namely, this treatment can be considered the best in this production year, under non-irrigated circumstances.

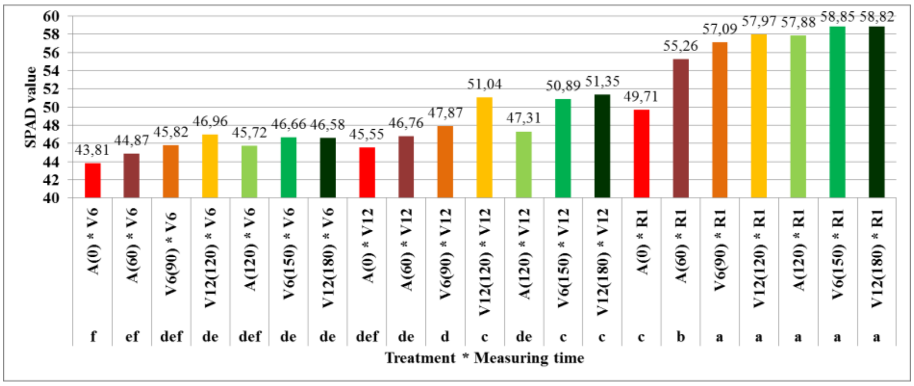

Figure 4: Effect of fertilisation and phenological phase on SPAD-values under non-irrigated circumstances in the average of genotypes (Látókép, 2012)

In the **2012** production year, relative chlorophyll concentration of maize has been influenced with 0.1% level of significance by basal fertilisation top dressing, phenological phase and their interactions. On the basis of the Student – Newman – Keuls test, the measured SPAD value was significantly ($P<0.001$) higher in every fertiliser treatment than on the untreated plot. Homogenous groups are marked with identical colours. The $A_{(60)}$ fertiliser treatment was statistically separable from the rest of the treatments. The $V6_{(150)}$, $V12_{(180)}$, $V12_{(120)}$, $A_{(120)}$ and $V6_{(90)}$ treatments have not differed significantly from each other.

The highest SPAD values have been measured within the R1 phenological phase (54.95), this was significantly ($P<0.001$) higher than the values measured in other phenological phases. The lowest statistically verifiable SPAD value was measured during the 6 leaf phase (45.45).

Relation of fertilisation and the phenological phase also affected SPAD values, the higher values have been measured in the R1 phenophase (Figure 5). The lowest SPAD values have been recorded during the 6 leaf phase in the $A_{(0)}$ treatment, which was not different from the values measured during 6 leaf phase in $A_{(60)}$, $V6_{(90)}$ and $V12_{(120)}$ treatments. Fertilised treatments ($A_{(60)}$, $V6_{(90)}$, $A_{(120)}$, $V12_{(120)}$, $V6_{(150)}$ and $V12_{(180)}$) have not differed from each other within this phase. During the 12 leaf phase, no verifiable difference was detectable among the $A_{(0)}$, $A_{(60)}$ and $A_{(120)}$ treatments. However, in this phenological phase, verifiably higher SPAD values have been measured in the case of the top dressed plots treated with $V6_{(90)}$, $V12_{(120)}$, $V6_{(150)}$ and $V12_{(180)}$ fertiliser doses than in the case of the $A_{(0)}$ treatment. Within the R1 phenological phase, fertiliser treatments have verifiably ($P<0.001$) differed from the SPAD values measured on the control plot, therefore the SPAD-scissors was opening, however the difference was not demonstrable amongst the fertiliser doses. The highest SPAD value was detected in the case of the $V6_{(150)}$ treatment (58.38).

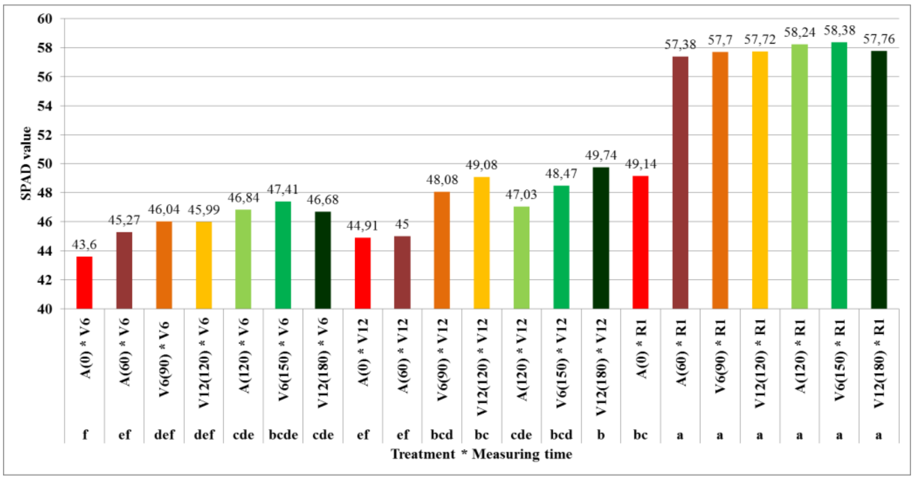

Figure 5: Effect fertilisation and phenological phase on SPAD values in the average of genotypes under irrigated circumstances (Látókép, 2012)

In **2013**, during the *6 leaf* phenological phase lower SPAD values have been measured on the non-fertilised control plots than on the fertilised plots (Figure 6). However, the 60 kg N ha^{-1} treatments had lower differences from the control plots than the plots treated with 120 kg N ha^{-1}.

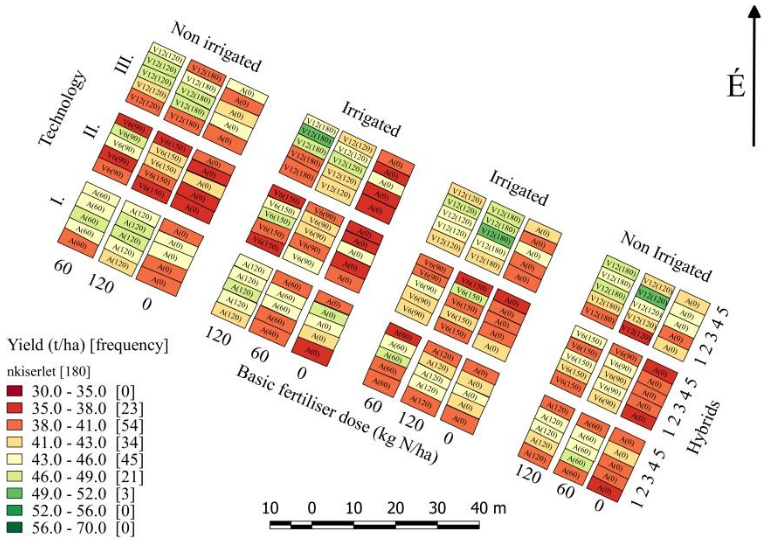

Figure 6: Spatial distribution of SPAD values in during the 6 leaf phase (Látókép, 2013)

During the *12 leaf* phenological phase, the difference between the control and the top dressing treatments has further increased, therefore the effect of the top dressing applied during the 6 leaf phase can also be recorded (Figure 7). In the case of the fertilised plots, the lowest chlorophyll content was measured for the $A_{(60)}$ treatment and the highest for the $V12_{(180)}$.

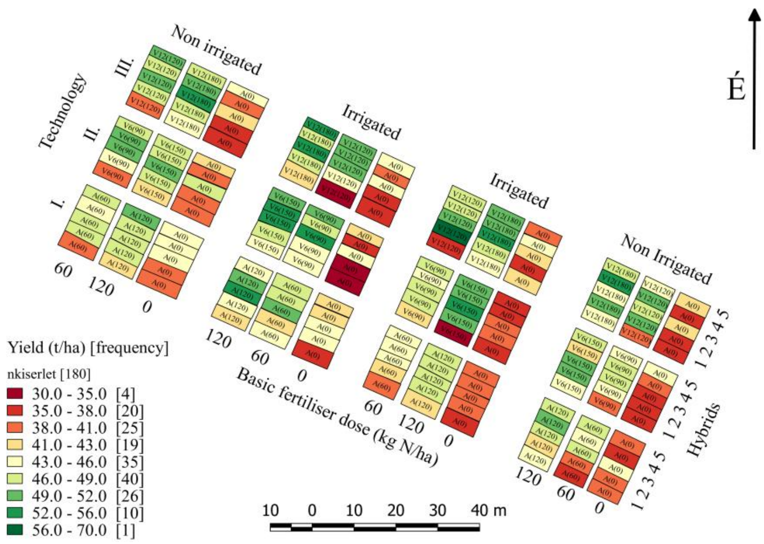

Figure 7: Spatial distribution of SPAD values during 12 leaf phase (Látókép, 2013)

During the *R1* phenophase, the SPAD increasing effect of the top dressing applied during the 12 leaf phase is already visible on the map in comparison with the control (Figure 8). The 120 kg N ha^{-1} + 60 kg N ha^{-1} + 60 kg N ha^{-1} treatment is well distinguishable from the rest of the fertiliser treatments.

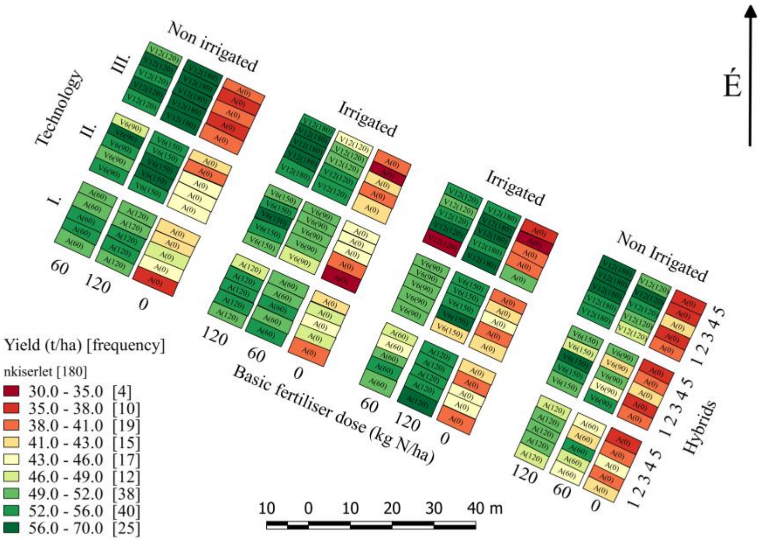

Figure 8: Spatial distribution of SPAD values during 50% silking (Látókép, 2013)

In the course of the statistical analysis the effects of basal fertilisation and top dressing on chlorophyll content have been examined separately under irrigated and non-irrigated circumstances. On *non-irrigated* plots, fertilisation treatments, phenological phases and their interactions have significantly ($P<0.001$) influenced the chlorophyll content of leaves. On the basis of the post hoc test results it has been found that the highest SPAD value (50.25) has been measured in the case of the $V12_{(180)}$ treatment. A significantly lower value has been measured in the case of the $V12_{(120)}$ treatment (2.08). There was no statistically detectable difference between the $V12_{(120)}$ and $V6_{(150)}$ treatments. However, every value measured in fertiliser treatments differed significantly from average values measured on the non-fertilised control plots.

According to the result of the repeated measurement model, chlorophyll concentration has increased in leaves over plant growth, the lowest value has been measured during 6 leaf phase (41.95). Values measured during 12 leaf phase are higher by 2.53 than the values measured in 6 leaf stage. The highest SPAD value (48.77) has been recorded during the 50% silking phase; it was significantly higher than the chlorophyll contents measured during the other two phenological phases.

Interaction of the phenological phase and fertilisation has significantly ($P<0.001$) affected SPAD values. In the figure, identical fertiliser treatments are marked with the same colour. The lowest SPAD values (40.3) has been recorded in 6 leaf phase with the $A_{(0)}$ treatment, namely on non-fertilised plots. Higher relative chlorophyll concentration in this phenophase has been measured in treatment group $A_{(60)}$, $A_{(120)}$, $V12_{(120)}$, and $V12_{(180)}$; there was no verifiable difference amongst the group members. During 12 leaf phase, significantly lower SPAD values have been measured in the $A_{(0)}$ treatment than in the case of the different fertiliser treatments. Higher values have been measured during the R1 phenophase; except for the non-fertilised control, which has not changed verifiably throughout the vegetation period (Figure 9). Therefore, the control and the fertilised treatments have opened the 'SPAD-scissor'. The highest value (58.49) has been measured during the R1 phase with the $V12_{(180)}$ treatment. Significantly lower value was recorded in the $V6_{(150)}$ treatment during the 50% silking phase (54.82), which did not differ significantly from the chlorophyll content measured in the $V12_{(120)}$ treatment (54.45). According to the post hoc test, the $V6_{(90)}$ and $A_{(120)}$ treatments formed a separate group in which significantly lower SPAD values have been recorded. The $A_{(60)}$ was not separable from either the $V6_{(90)}$, or the $A_{(120)}$ treatments in terms of the SPAD values measured during the R' phase and the 12 leaf phase values of the $V12_{(180)}$ treatment. This can be explained by the fact that in the $V12_{(180)}$ treatment 120 kg N ha^{-1} basal fertiliser and 30 kg N ha^{-1} top dressing was applied during the 12 leaf stage.

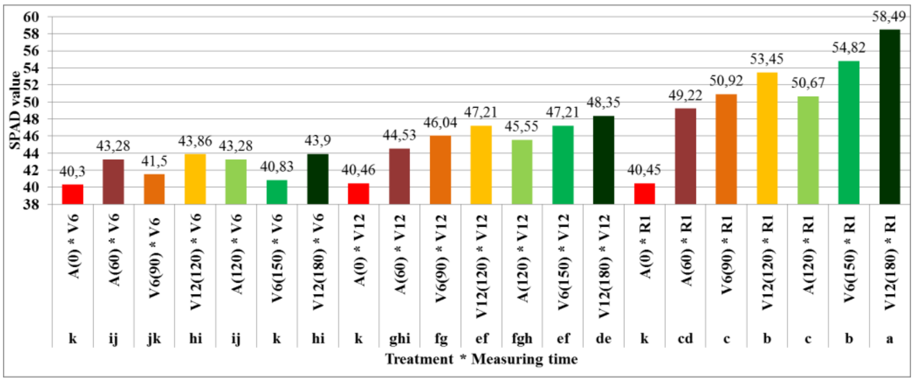

Figure 9: Effect of fertilisation and phenological phase on SPAD values under non-irrigated circumstances in the average of genotypes (Látókép, 2013)

Under *irrigated* circumstances in **2013,** fertiliser doses, the phenological phase and their interactions affected the relative chlorophyll concentration of maize leaves at 0.1% significance level. This year, the highest SPAD values under irrigated circumstances have been measured in the $V12_{(180)}$ treatment (50.21), which had the largest fertiliser dose. This value verifiable (P<0.001) differed from the rest of the treatments (Figure 35). There was no statistically detectable difference amongst the $A_{(120)}$, $V12_{(120)}$ and $V6_{(150)}$ treatments. The $V6_{(90)}$ and $A_{(60)}$ treatments – which had lower fertiliser doses – form a separate group. The lowest SPAD value has been measured on the non-fertilised control plot (40.36).

Phenological phase verifiable affected SPAD values at 0.1% level of significance; the highest has been measured during the R1 phenophase (48.89) in 2013 on irrigated plots.

SPAD values measured in different phenological phases were verifiably different, the lowest value was measured during 6 leaf stage (41.78).

Interaction of fertilisation and the phenological phase have verifiably affected SPAD values. During the vegetation period, higher SPAD values have been measured on fertilised plots in comparison with the control plots; namely the SPAD-scissors opens (Figure 20). The lowest SPAD values have been measured during 6 leaf phase, where $A_{(0)}$, $A_{(60)}$, $V6_{(90)}$ and $V6_{(150)}$ treatments were not separable from either each other, or the values measured on control plots during the 12 leaf phase. There was no detectable difference between the SPAD values measured during the 6 leaf stage, in $A_{(120)}$, $V12_{(180)}$ treatments and 12 leaf stage in the $A_{(60)}$ treatment, however they have significantly differed from the rest of the groups. The highest SPAD value was recorded during the R1 phase in the case of the $V12_{(180)}$ treatment, which had the highest fertiliser dose (56.63). During the R1 phenophase, the $A_{(120)}$, $V12_{(120)}$ and $V6_{(150)}$ treatments formed a separate group and they significantly differed from the chlorophyll contents measured in the rest of the phenophases. The colours mark different fertiliser treatments in the figure.

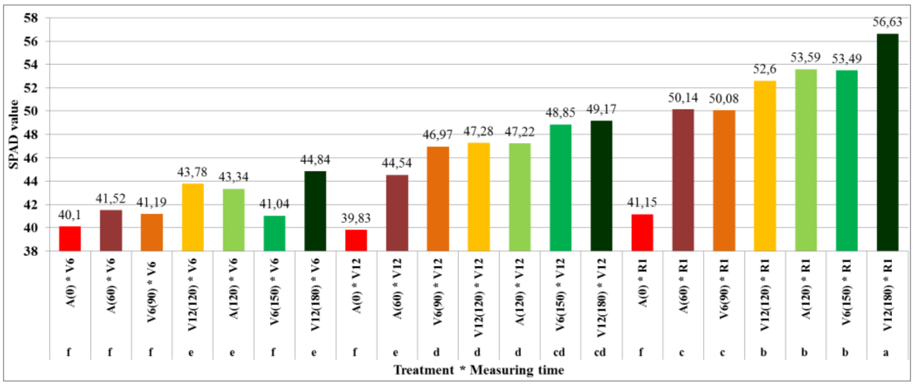

Figure 10: Effect of fertilisation and the phenological phase on SPAD values under irrigated circumstances in the average of genotypes (Látókép, 2013)

In **2014**, during the *6 leaf* phenological phase, lower SPAD values have been measured on the control plots than on the fertilised plots (Figure 11). The results of the plots treated with $V6_{(150)}$ and $V6_{(90)}$ can be separated the most from the control plots. However, there was no difference in comparison with the control in the case of the $A_{(120)}$ treatment.

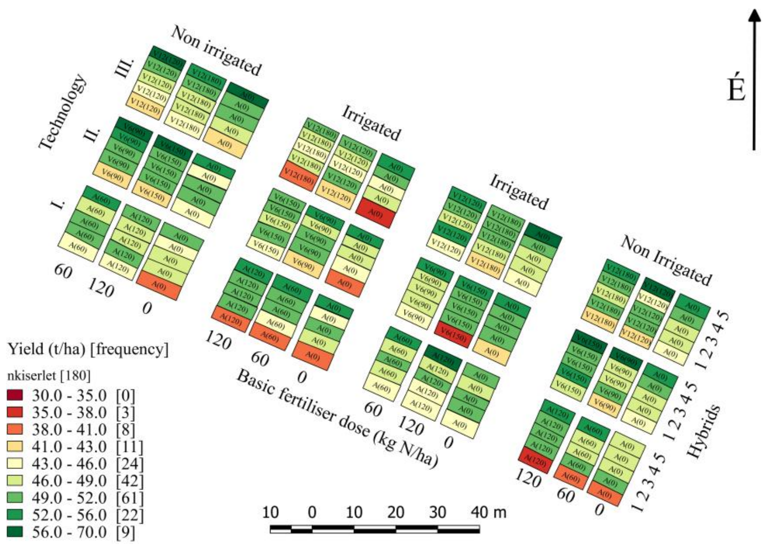

Figure 11: Spatial distribution of SPAD values during the 6 leaf stage (Látókép, 2014)

During the *12 leaf* phenological phase the difference between the control and the fertiliser treatments is already visible, since the fertiliser applied during the 6 leaf phase has already been utilised (Figure 12). The highest values have been recorded in the $V12_{(180)}$ treatment and here extremely high SPAD values have been measured in comparison with the rest of the treatments.

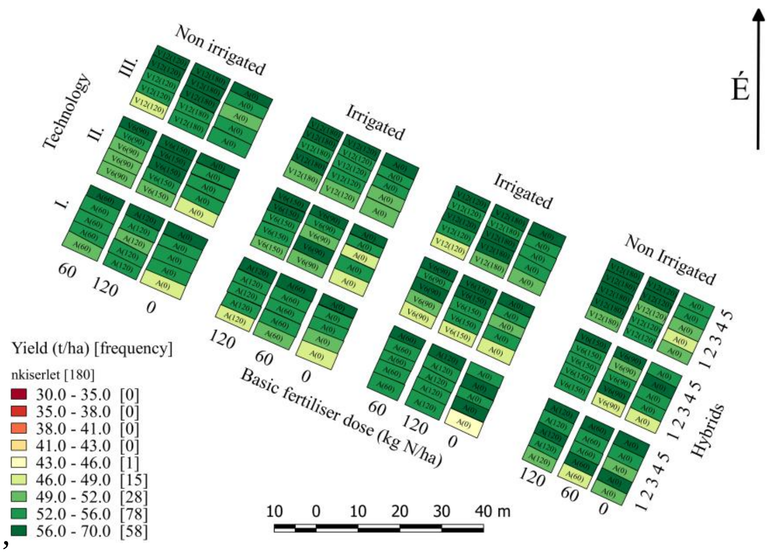

Figure 12: Spatial distribution of SPAD values during the 12 leaf phase (Látókép, 2014)

During the *R1* phenophase, measured SPAD values further increased in the $V6_{(90)}$ fertiliser treatment in comparison with the 12 leaf phase. However, a decline is experienced in terms of SPAD values in the rest of the treatments; the largest decline was recorded in the $A_{(0)}$ treatment. Thus, the values of the $V6_{(90)}$ treatment are similar to the ones measured in $V12_{(180)}$ which had the largest fertiliser doses (Figure 13).

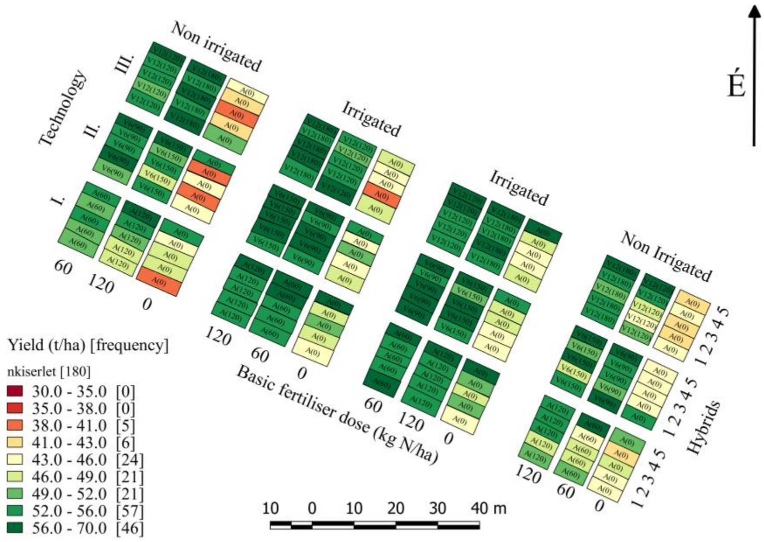

Figure 13: Spatial distribution of SPAD values during the 50% silking phase (Látókép, 2014)

According to the results of the statistical model, the fertiliser doses, phenological phases and their interactions affected the measured SPAD values at level of significance of 0.1% under *non-irrigated* circumstances. According to the result of the post hoc test, the highest SPAD value has been measured that year – under non-irrigated circumstances – in the case of the $V12_{(180)}$ treatment (53.82), which was significantly higher than SPAD value of the $A_{(120)}$, $A_{(60)}$ and $A_{(0)}$ treatments. Values measured in the case of the $V6_{(150)}$, $V6_{(90)}$ and $V12_{(120)}$ fertiliser treatments have not differed significantly from the $V12_{(180)}$, $A_{(120)}$ and $A_{(60)}$ treatments. The highest statistically verifiable SPAD value has been measured on the untreated control plots (48.82).

SPAD values have been affected by the phenological phase, the colours in the figure mark homogenous groups. The lowest verifiable SPAD values have been measure during the 6 leaf phase (48.86). In the course of maize growth, chlorophyll concentration of the leaves has increased; it reached its peak in the 12 leaf phase (54.42). However, by the time of the 50% silking chlorophyll concentration of the leaves has significantly ($P<0.001$) decreased (50.72). This symptom indicates the drying of the plant, since the 6.7 mm precipitation in June proved to be insufficient even with the 35.5 mm irrigation water.

In 2014, under non-irrigated circumstances SPAD values have increased between the 6 leaf stage and the 12 leaf stage, and then they started decreasing in every fertiliser treatment (except for the $V6_{(90)}$) and the control plot. The highest chlorophyll concentration has been measured in 12 leaf stage in the case of the $V12_{(180)}$ treatment (largest fertiliser dose) (56.84). However, the measured values of the $V12_{(180)}$ treatment have not differed significantly from the values of $V6_{(150)}$, $V12_{(120)}$, $A_{(60)}$ during 12 leaf phase and $V12_{(180)}$ and $V6_{(90)}$ treatments during R1 phase. The values of the $A_{(60)}$, $A_{(120)}$, $V6_{(90)}$, $A_{(0)}$ treatments measured in 12 leaf phase have been significantly lower than the SPAD values of the $V12_{(180)}$ treatment. In the 6 leaf phase, the values measured in the case of different fertiliser treatments were not statistically separable from each other (Figure 14). The lowest values have been measured on the non-fertilised plots, however – unlike the previous two years – in the R1 phase instead of the 6 leaf phase (45.08). These have significantly differed from the values measured in other phenophases and they have been lower by an average 3.15 SPAD value than the values of the $A_{(0)}$ treatment measured during the 6 leaf phase. The colours in the figure mark identical fertiliser treatments.

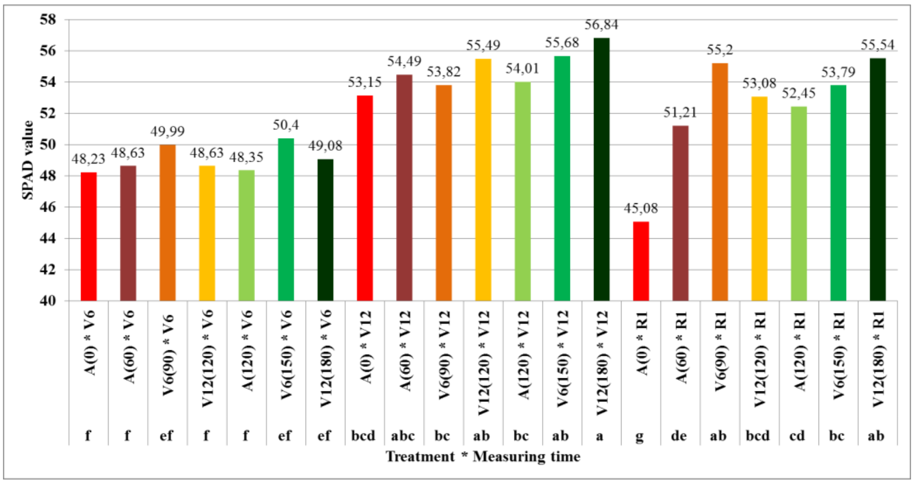

Figure 14: Effect of fertilisation and phenological phase on SPAD values under non-irrigated circumstances (Látókép, 2014)

Under *irrigated* circumstances, fertiliser treatments, phenological phases and their interactions had a statistically verifiable effect ($P<0.001$) on the SPAD values. In this production year, there was no detectable difference amongst the different fertiliser doses. The fertilised plots differed significantly from the untreated control plots.

Similarly to the rest of the production years, the lowest SPAD value (48.39) has been measured during the 6 leaf phase. However, unlike in the other production years, the highest SPAD value (54.54) has been measured during the 12 leaf phase; this value has significantly differed from the values measured in the other two years.

The interaction of fertiliser doses and the phenological phase also influenced SPAD values; the values of every treatment measured during the V6 phenophase have not differed verifiably (Figure 15). During the 12 leaf phase, the measured values of the $A_{(0)}$, $V12_{(120)}$,

$A_{(60)}$, $V6_{(90)}$, $A_{(120)}$, $V6_{(150)}$ treatments have not been separable. In this phenophase, the $V12_{(180)}$ fertiliser treatment resulted in statistically higher SPAD values in comparison with the $A_{(0)}$ treatment. During the R1 phenophase, every fertilise treatment had higher relative chlorophyll concentrations than the untreated control plots. There were no detectable differences amongst the fertiliser treatments during the R1 phenophase, the highest SPAD value (58.1) has been detected in the $V6_{(90)}$ treatment. The colours in the figure mark identical fertiliser treatments.

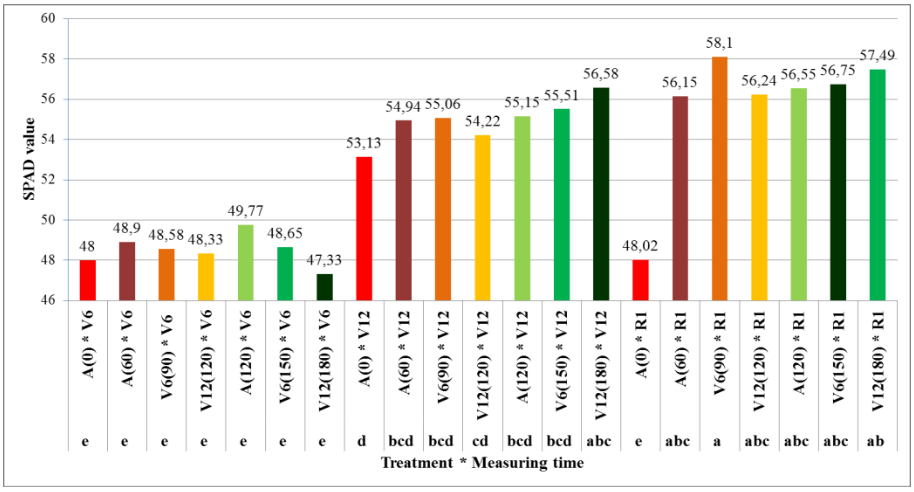

Figure 15: Effect of fertilisation and the phenological phase on SPAD values under irrigated circumstances in the average of genotypes (Látókép, 2014)

3.2. EFFECT OF BASAL FERTILISATION, TOP DRESSING AND THE PRODUCTION YEAR ON MAIZE YIELD

The relation amongst fertilisation, production year and yield has been analysed by means of a repeated measurement model. The effect of fertilisation and production on yield year has been detectable at 0.1% level of significance, while the interaction of these two parameters was ineffective. Similarly to the four year trial results of *Berenguer et al.* (2008) in our three year trial, production year and fertilisation influenced the yield of maize, but in our case, their interaction had no effect on the yield. All six fertiliser treatments have significantly ($P<0.001$) differed from the non-fertilised treatment, similarly to the results of *Rátonyi et al.* (2014). The highest yield in the average of three years (13.3 t ha^{-1}) has been achieved with the by the $V6_{(150)}$ treatment, with 120 kg N ha^{-1} basal fertilisation + 30 kg N ha^{-1} top dressing. This significantly differed from the 60 kg N ha^{-1} basal fertilisation treatment. $V12_{(180)}$, $A_{(120)}$, $V6_{(90)}$ and $V12_{(120)}$ treatments have not differed significantly from the $V6_{(150)}$ and $A_{(60)}$ treatment. This tendency, where the increase of nitrogen fertiliser does not increase yield above a certain dosage is similar to the results of *Vad and Dóka* (2009) and *Dóka and Pepó* (2007).

All three analysed years have significantly ($P<0.001$) differed from each other; the highest yield – in average of the treatments – has been measured in 2012. This was a droughty year, however precipitation in May, June and July was more than the multi-annual average; this contributed to the achievement of the 13.2 t ha^{-1} yield. Amongst the analysed years, the second highest yield has been measured in 2014, which was 11.3 t ha^{-1} in average of the trial. In July, double of the multi-annual average precipitation amount has fallen, which has slightly decreased the effect of drought in June. The lowest yield (10.7 t ha^{-1}) was in 2013, in May there was 30% more precipitation than the multi-annual average; however the following strong drought and late irrigation after flowering had negative effects on yield.

Interaction between production year and fertilisation was not significant under non-irrigated circumstances; however the interaction graph is suitable for summing up the analysed years (Figure 16). Amongst the three analysed years, in 2012 and 2013 the $V6_{(150)}$ treatment proved to be the best in terms of yield, however it has not differed significantly from the $A_{(120)}$ treatment. In the three analysed years top dressing above 120 kg N ha^{-1} basal fertilisation did not have any effect on yield, however in the three analysed years similarly to the results of *Berényi et al.* (2007) the 120 kg N ha^{-1} basal fertilisation resulted in verifiably yield growth.

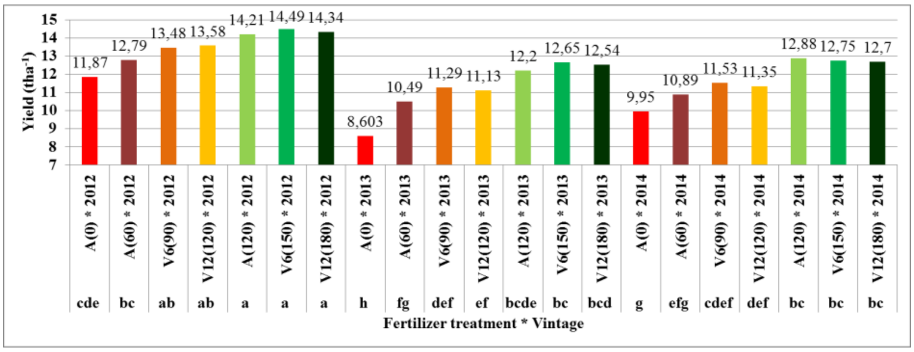

Figure 16: Effect of basal fertilisation and top dressing and the production year on yield in the average of genotypes under non-irrigated circumstances (t ha-1) (Látókép, 2012–2014)

3.3. ANALYSIS OF THE CONNECTION BETWEEN RELATIVE CHLOROPHYLL CONTENT AND YIELD

Considering that multiple researchers *(Schepers et al.*, 1992; *Piekielek and Fox*, 1992; *Berzsenyi and Lap*, 2003a; *Ványiné*, 2008; *Ványiné and Nagy*, 2012) found the SPAD-502 device suitable for yield estimation and the monitoring of N-supply of maize (on the basis of the SPAD values in leaves), in present case, also a regression analysis has been performed for the chlorophyll concentrations measured in different phenological phases and yield..

3.4. CONNECTION OF SPAD VALUES MEASURED IN DIFFERENT PHENOLOGICAL PHASES AND YIELD

In the average of the three analysed years the connection of SPAD values measured in each phenological phase and yield has been weak during the 6 leaf phase. Values measured in the case of the irrigated variant shoed stronger connection than in the case of the non-irrigated variant. Results measured during the 12 leaf phase showed similarly weak connection. However, in this case the connection of the non-irrigated variant has been stronger than that of the irrigated one. During the R1 phenophase there was a medium close connection between SPAD values and yield. In this phenophase the non-irrigated plots had a greater influence on yield results than the irrigated plots. Similarly to the results of *Nagy* (2010) the connection was weak between chlorophyll content and yield in the non-irrigated variant. However, in this case the connection between SPAD values and yield was also weak in the irrigated variant as well. Since the determination coefficients fell behind the r^2 results of *Berzsenyi and Lap* (2003a) measured during the R1 phenophase (30.4-36.8% in 5 year average), the connection of maize leaf chlorophyll concentration and yield has been analysed annually.

3.4.1. Connection of SPAD values measured in different phenological phases and yield in 2012

The connection between SPAD values measured during 66 leaf phase – under non-irrigated circumstances – and yield in 2012 has been week (r=0.372), the measured maize leaf chlorophyll concentrations had a 13.9% influence on yield results (P<0.001). Connection between SPAD results measured under irrigated circumstances during the 6 leaf phase and yield has been medium close (r=0.583). SPAD values have influenced yield results in 33.9% (P<0.001).

Connection between SPAD results measured under non-irrigated circumstances during the V12 phenophase and yield has been weak (r=0.361), SPAD values measured in this phenological phase influenced yield in 13% (P<0.001). SPAD values measured under irrigated circumstances during 12 leaf phase had a weak connection (r=0.366) with yield, and they influenced yield results in 13.4% (P<0.001).

Connection between SPAD values measured under non-irrigated circumstances during the R1 phenophase and yield has been weak (r=0.398), the measured values influenced yield in 15.9% (P<0.001). Under irrigated circumstances during the R1 phenophase at 0.1% level of significance there was a close connection (r= 0.441) between yield and SPAD values. This value falls behind the r^2 results of *Berzsenyi and Lap* (2003a) measured during the R1 phenophase (30.4-36.8% in 5 year average), however there was a close connection with the results of *Blackmer and Schepers* (1996).

3.4.2. Connection of SPAD values measured during different phenological phases and yield in 2013

In 2013, during the 6 leaf stage under non-irrigated circumstances and at 0.1% level of significance a medium close (r=0.447) connection has been confirmed between the SPAD values and maize yield. SPAD values have influenced maize yields in 19.9%. Under irrigated circumstances during the 6 leaf phase there was a medium close relation (r=0.445) between SPAD values and yield results. The measured SPAD values influenced yield in 19.8% at a 0.1% level of significance.

Under non-irrigated circumstances during the 12 leaf phase the connection between SPAD values and yield has been close (r=0.781). The measured chlorophyll concentrations influenced maize yields in 61% (P<0.001).During the 12 leaf phase under irrigated circumstances the measured maize leaf chlorophyll concentrations have shown a close correlation (r=0.692) with yield. SPAD values have influenced yield in 48% at a 0.1% level of significance.

SPAD values measured under non-irrigated circumstances, during 50% silking had a medium correlation (r=0.653) with yield results (P<0.001). The measured chlorophyll concentration influenced maize yield in 42.7%. Regression analysis resulted in a medium close correlation during the R1 phenophase (r=0.572) in terms of the chlorophyll concentration of maize (P<0.001). SPAD values have influenced yield in 32.8%. These results are similar to the r^2 result of *Berzsenyi and Lap* (2003a) measured during the R1 phenophase in the average of 5 years (30.4-36.8%).

3.4.2. Corellation of SPAD values measured in different phenophases and yield in 2014

In the case of the analysed year, during the 6 leaf phase there was no verifiable correlation in either the irrigated or the non-irrigated variant between the relative chlorophyll concentration of maize leaves and yield.

Under non-irrigated circumstances during the 12 leaf phase, there was a very weak correlation (r=0.184) between SPAD values and maize yield at 5% level of significance. The measured relative chlorophyll concentrations influenced maize yield in 3.4%.

There was a weak correlation (r=0.203) between SPAD values and yield results in 2014 during the 12 leaf phase ($P<0.05$). Relative chlorophyll concentrations of maize leaves influenced yield in 4.1%.

During the 50% silking phase in the non-irrigated variant a very weak correlation has been found between SPAD values and yield (r=0,203) ($P<0,05$). The measured maize leaf relative chlorophyll concentrations influenced yield in 4.1%. In the case of the irrigated variant during the R1 phenophase there was a weak (r=0.286) correlation between the measured SPAD values and maize yield. The analysed leaf chlorophyll concentrations influenced the yield in 8.2% at 1% level of significance. In both the irrigated and non-irrigated variants, this correlation result has shown a similar tendency to the low ($r^2=0.05$) correlation coefficient result of *Blackmer and Schepers* (1996). However this result is contradictory with the results of *Piekelek and Fox* (1992), and *Berenguer et al.* (2009).

3.5. N-FERTILISATION TECHNICAL ADVICE ON THE BASIS OF SPAD MEASUREMENTS CARRIED OUT ON REFERENCE AREAS

Environmental pressure of nitrogen fertilisation is the largest amongst macro elements. Excessive nitrogen fertilisation contaminates underground waters and it might cause eutrophication in surface waters. Economic yields and as little environmental pressure as possible is ensured by the proper dosing of nitrogen.

The final objective of our research was the decision-support of farmers. It includes the validation of reference area-based (*Pakurár et al.,* 2003; *Schröder et al.,* 2000; *Ványiné*, 2008) nitrogen fertilisation based on small-plot measurement data which might complete nutriment management plans. The basis of the method is that a small sample area is formed on the given plot which is well supplied with nitrogen. Compared to the reference area, the SPAD values measured on the target area are well supplied within the limit of 98% (*Ványiné*, 2008), 92-95% according to *Schröder et al.* (2000) and *Blackmer and Schepers* (1995) and *Piekielek et al.* (1995), and 95% according to *Shanahan et al.* (2008). For the calculations of present thesis the method of *Ványiné* (2008) has been used, 6kg multiplier in non-irrigated cases and 9kg multiplier under irrigated circumstances.

$$100 * \frac{\text{Ref-T}}{\text{Ref}} * 6 \ \ (\text{kg N ha}^{-1})$$

$$100 * \frac{\text{Ref-T}}{\text{Ref}} * 9 \ (\text{kg N ha}^{-1})$$

Where:
Ref: SPAD value measured on the reference area
T: SPAD value measured on the plot to be fertilised

Calculations have been carried out with a 98% SPAD-value difference, which means that there is nothing to be done below a 2% difference, while above it 6kg N ha^{-1} (non-irrigated) and 9kg N ha^{-1} (irrigated) fertiliser was calculated for every 1% difference. The calculations have been carried out with a reference area treated with 60 kg N ha^{-1} and 120 kg N ha^{-1} basal fertilisation in the average of the analysed years and in the analysed production years as well. Nitrogen fertiliser ensuring proper N-supply shall be applied to the reference area in spring, before sowing. SPAD measurements are reasonable to be carried out before the use of a cultivator, during the *6 leaf* phenological phase. Top dressing is to be done with a cultivator with doses calculated with the help of the reference area.

Under non-irrigated circumstances 19 kg N ha^{-1} would have been necessary in the average of three years in comparison with the 60 kg N ha^{-1} control plot. On the non-fertilised control plot, the 120 kg N ha^{-1} basal fertilisation should be completed by 22 kg N ha^{-1} active ingredient to reach the 98% reference level. In the case of the rest of the fertiliser treatments, no top dressing was necessary.

Our calculations have been carried out with values measured during the *12 leaf* phase on the basis of the data from the three analysed years in order to observe the effect of top dressing applied during the 6 leaf phase. Under non-irrigated circumstances, during the 12 leaf phase, the top dressing demand on control plots as increased to 28 kg N ha^{-1}-ra for the 60 kg N ha^{-1} basal fertiliser level. Using the 120 kg N ha^{-1} reference area, the calculated top dressing demand of the control plots has increased to 38 kg N ha^{-1}. During the 12 leaf phase, the plots fertilised with 60 kg N ha^{-1} demanded 11 kg N ha^{-1} top dressing for reaching the reference level. The effect of the 30 kg N ha^{-1}applied during the 6 leaf stage in the case of the

$V6_{(90)}$ is detectable. Top dressing demand of the $V6_{(90)}$ is 1.36 kg N ha^{-1}, which is 9.33 kg N ha^{-1} less than that of the $A_{(60)}$ treatment.

Under irrigated circumstances, in the average of the analysed three years 24 kg N ha^{-1} fertiliser is required on the control plots for reaching the reference level of the 60 kg N ha^{-1} basal fertilisation. For reaching the reference level of the 120 kg N ha^{-1} basal fertilisation the control plots required 50 kg N ha^{-1}top dressing, for the 60 kg N ha^{-1} basal fertiliser dose 26 kg N ha^{-1}, while in the case of the $V6_{(90)}$ treatment 22 kg N ha^{-1} top dressing should be applied. In terms of the 6 leaf phenological phase, $A_{(60)}$ and $V6_{(90)}$ treatments can be considered identical, since top dressing took place following the SPAD measurements.

Under irrigated circumstances, during the 12 leaf phase, the top dressing demand of control plots is 39 kg N ha^{-1}, which is 14 kg N ha^{-1} more than during the 6 leaf phase. Using the 120 kg N ha^{-1} reference, the top dressing of the $V6_{(90)}$ treatment applied during the 6 leaf stage is detectable. Top dressing demand of the treatment in 12 leaf phase zero compared to the 6 leaf phase.

3.6. DEVELOPMENT OF THE SPATIAL AND TEMPORAL STORAGE OF THE DATA OF LONG-TERM FIELD TRIALS

In the case of long-term trials, treatments might change and plot merging is also possible. Therefore it might be difficult to refer the lines of the database to certain plots. Within this chapter a development possibility is presented towards fellow researchers dealing with long-term field trials for the GIS visualisation of their own measurement data. By means of the self-elaborated R script, the previously completed database is relatively easy to connect to the outline of the trial created in Quantum GIS. Thus, the GIS database with its large amount of easily attachable data provides a solution for the often problematic spatial and temporal identification of each plot. Consequently, the trial and any occurring change become easier to be monitored. The existing database is exportable in multiple formats, including an *xml* based *kml* format, which can be displayed in Google Earth.

This programme platform is independent, however it requires installation and it is not editable. Another solution is the display of previously created *.kml* files on the „*Google Drive*"-on, by importing them into the „*Google My Maps*" application, where the map can be visualised within the web browser Also, „*Google My Maps*" is available for Android mobiles and tablets, therefore – depending on the GPS accuracy of the device – it is possible to navigate within the trial on plot level. It is important to point out that the software requires an intern connection.

These maps can be shared within the researcher group my means of Goole Drive, and also their outline can be edited and it is possible the fill empty columns of the attribute table with measurement data.

The completed GIS database can not only be used as an exported *kml*, but it is also suitable for presentation purposes. In *Open Layers Plugin* which is available cost-free for QGIS, the *Google Satellite* layer has been used (*Google*, 2016) for visualisation. Data is categorised by the software and is coloured on the basis of user demand.

4. NOVEL SCIENTIFIC RESULTS

1. In the average of the three analysed years, it has been found that SPAD values has been mostly increased by the 120 kg N ha^{-1} basal + 30 +30 kg N ha^{-1} top dressing under non-irrigated circumstances, while in the irrigated variant by the 120 kg N ha^{-1} basal fertilisation.
2. It has been confirmed that SPAD values alone cannot be used for yield estimation; however a tendency has been found where correlation between SPAD values and yield strengthens with the advance of the phenological phase.
3. The effect of the 30 kg N ha^{-1} op dressing during the 6 leaf phase has been confirmed my means of the described method. On the basis of well supplied small reference areas the top dressing demand of maize can be determined during the 6 leaf phase and the method is suitable for controlling the effects after application.
4. An application has been further developed for the spatial and temporal storage of the data of long-term field trials, which might support the data processing of research and the presentation of data. On the basis of the resulting distribution maps, work hypotheses can be set up.

5. PRACTICAL USEFULNESS OF THE RESULTS

By means of the described method, the effect of the 30 kg N ha^{-1} top dressing applied during the 6 leaf phase has been demonstrated; therefore the method is justified. By means of the method, top dressing demand of maize can be determined during the 6 leaf phase on the basis of an excessively fertilised small plot. Following the application of the fertiliser, its effect is also controllable. On the basis of demands calculated based on the measurements, a second or – in the case of proper water supply - a third top dressing can also be applied by means of a JD 4730 + „Yetter" disc, which is able to solve nutriment supply up to a 1.8 m plant height.

In terms of economics, the most favourable result has been recorded under non-irrigated circumstances in the $V6_{(90)}$ treatment. Under irrigated circumstances, the A_{120} treatment was the most optimal economically, however it was unfavourable in terms of cultivation technology. Irrigation during the analysed three years – since its yield improving effect was not significant – had an economically negative result. On the basis of our results, 60 kg N ha^{-1} basal fertiliser and 30 kg N ha^{-1} top dressing are the most recommended in both irrigated and non-irrigated cases.

A method has been elaborated for the development of the spatial and temporal storage of the long-term field trials, which might facilitate data processing of research activities and the presentation of data. Work hypotheses can be set up on the basis of the elaborated distribution maps.

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List of publications related to the dissertation

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